Rivista di biologia – Biology Forum **82** (1), **1989, 39-59**

Limits to reductionism in biology*

Franz M. WUKETITS**

> Organisms are not just heaps of molecules. At least, I cannot bring myself to feel like one. Can you?
>
> P. A. WEISS (1969)

ABSTRACT: Science has been done most successfully by analysing and 'decomposing' the structures of nature, and reduction is said to be the most successful research strategy in almost every branch of science. Besides being a research strategy, however, reduction reductionism has been criticized for ontological reasons: According to the reductionists' credo complex systems like organisms are indeed nothing else but heaps of molecules or even atoms. Thus, the reductionism controversy has endured. In the present paper I am discussing the types of reduction reductionism and, particularly, the limits to reductionism in biology. My argument is that holism is still the alternative approach to reductionism. Hence, in a way, this paper is also a plea for intensifying synthetic thinking.

1. INTRODUCTION

Discussing reduction might seem like flogging dead horses. Can there be any doubt that «reductive analysis is the most successful stratagem ever devised» (MEDAWAR and MEDAWAR, 1983, p. 227)? And can any scientist doubt that, to give a fairly

*Paper presented at the «XIV International Botanical Congress» (Symposium 7-02 «Ways in Biological Thinking») in Berlin 1987.

**Institute of Philosophy, University of Vienna, A-1010 Vienna, Austria.

known example, the structure of the DNA –and thus the chemistry of a most fundamental biological process– was illuminated by the means of analytical (reductive) methods? Yet there are many questions concerning the scope and the limits of reduction/reductionism in science, particularly in biology. Misunderstandings and confusions are due to the fact that actually there are different types of reduction/reductionism and that, accordingly, reduction/reductionism can be applied to the study of living beings in different ways. Therefore it might be useful to revisit this old and venerable issue. Besides, since many biologists are still ontological reductionists, it is necessary to show that they trust in blatant metaphysical doctrines. It is true that

> reductionism as a strategy of scientific explanation is motivated by both the desire for and the promise of a unified science that economizes on types of entities and laws» (JACOBS, 1986, p. 389).

But I suppose that this desire is frequently ruled by the metaphysical belief that nature can be 'decomposed' and that then, having the elements and particles, we shall be in the position to know everything and anything about nature's intrinsic character and even to control its development.
In this paper I am going to given a brief survey of types of reduction/reductionism and reductionistic research strategies in biology. My primary concern, however, is to show the limits to (ontological) reductionism in the life sciences and to pose some arguments for holism.

2. TYPES OF REDUCTION/REDUCTIONISM IN SCIENCE

Reductionism in science means –most generally speaking– the doctrine that systems or their states can be reduced to their components and that an understanding of the properties and laws of the components will prompt us to understand the properties and laws at the systems' level (RIEDL, 1985). In his essay «Scientific Reduction and the Essential Incompleteness of All Science» POPPER (1974, p. 260) suggests

> that scientists, whatever their philosophical attitude towards holism, *have* to welcome reductionism as a *method*: they have to be either naive or else more or less critical reductionists; indeed, somewhat desperate critical reductionists...

> because hardly any major reduction in science has ever been *completely* successful: there is almost always an unresolved residue left by even the most successful attempts at reduction.

However that might be, Popper has in mind different types of reduction. And actually reduction/reductionism appears at least at three levels. According to AYALA (1974) the notion of reduction can be subdivided into three senses, namely *ontological*, *methodological* and *epistemological* reduction (see also HOYNINGEN-HUENE and WUKETITS, 1987; SATTLER, 1986; WUKETITS, 1983).

Ontological reduction implies that all phenomena in the inorganic as well as in the organic world can be reduced to phenomena of ever-less complexity. Hence mental and psychic phenomena can be reduced to organic entities, these entities are reducible to molecular structures and functions, and, finally, to atoms (or even elementary particles). If one argues as an ontological reductionist, he (she) will be convinced that psychology is reducible to biology, biology to chemistry, and chemistry to physics. That means that, *vice versa*,

> the laws of physics fully apply to molecular, organic (organismic), and psychic (mental) processes; living systems (even humans), then would be nothing else but heaps of atoms (WUKETITS, 1987, p. 320).

Obviously, ontological reductionism is based on the philosophical –or rather metaphysical– belief that the properties of living systems can be fully described when reduced to their constituents at the molecular (chemical) and atomic (physical) level. The attitude of ontological reductionists is rather naive; their belief is based on the 'nothing but' fallacy (see DOBZHANSKY et al., 1977; LORENZ, 1978; SATTLER, 1986). This is the fallacious idea that because a phenomenon consists of 'something else' it is *nothing but* this 'something else'. Living systems indeed consist of atoms and molecules, «but it does not follow that they are nothing but heaps of atoms and molecules» (DOBZHANSKY et al., 1977, p. 489).

The second type of reduction, methodological reduction, is something like a research strategy and has nothing to do with philosophical (ontological) arguments. Methodological reductionism is a 'pragmatical reductionism' (RIEDL, 1985) and means to investigate processes and laws at lower levels of complexity. If an anatomist is going to study the 'composition' of, for instance, the respiratory organs in arthropods, he (she) will of course 'decompose' these organs in order to see how they

are structured. Analysing, 'decomposing' organisms, organs and other parts of living systems has been an important and most successfully applied method in the life sciences. I shall discuss this method in the next section of the present paper.

Having stated what ontological and methodological reduction means, one can say now that these types of reduction appear at rather different levels of biological research: ontological reduction concerns most general philosophical premises, whereas methodological reduction is just a working method used by any biologist in his (her) laboratory.

Now some words about epistemological reduction (or *theory-reduction*). This type of reduction has neither to do with ontology, nor with mere empirical research. It implies the argument that theories and laws formulated in one branch of science can be demonstrated as special cases of theories and laws in another field of research. Epistemological reduction hence means that a theory (or law) formulated in one branch of science (e.g. biology) must be derived as logical consequence from the theory (or law) to which it is reduced (*derivability*), and that the concepts which are used in this branch of science must be defined in terms of the science to which they are reduced (e.g. physics) without loss of meaning (*connectability*) (see, for details, NAGEL, 1961). Epistemological reduction might be seen as an indicator of 'scientific progress'. Epistemological reduction means indeed that a theory (or law) can be reduced to more comprehensive theories (or laws), i.e. to theories (or laws) of a far-raching 'explanatory power'. The most comprehensive and universal theories and laws are those of physics. Does epistemological reduction, then, mean that biologists should try to reduce their theories (and laws) to the theories (and laws) of physics? And does this type of reduction mean that biologists should use the concepts of physics? Let me state at once that biology, some way or other, is an autonomous discipline (see AYALA, 1968; SATTLER, 1986; WUKETITS, 1978, 1983). That means that a biologist studies properties of systems –e.g. sexual behaviour in mammals– which are not exclusively ruled by physical laws (although there are actually physical *constraints* upon them). Besides, I cannot see any sense in describing and explaining, say, courtship behaviour in birds exclusively in terms of physics. Do you know any physical term which would fit courtship behaviour? MOHR (1977, p. 104-105) writes:

> Not only is there no reason to eliminate biology as an independent discipline in favor of physics; there is also no reason to reduce the diversity of scientific

approaches within biology as long as these approaches are scientifically sound *and productive*. If, however, a field becomes dominated by rigid paradigms with a concomitant shortage of new ideas, a drive for reduction can stimulate a revolution! Classical and molecular genetics are good examples.

Finally one word about what POPPER (1974) calls philosophical reduction. That is the credo of idealistic philosophy, according to which any real object is reducible to its 'essence' (whatever that might be). I do not think that there is much in this credo. It rather has hampered scientific and philosophical progress. Clearly, this kind of reduction offers no ideas which might be useful in biology.

3. REDUCTIONISTIC RESEARCH STRATEGIES IN BIOLOGY

Every biologist –or at least every efficient biologist– has experienced that reductionistic research strategies are crowned with success. Let me give a few examples. (By reductionistic 'research strategies' in this context I have in mind both *methodological* and *epistemological* reduction). With regard to methodological reduction it may suffice to remember that –except for those who are just 'contemplating' about nature– anybody who wants to get a deeper insight into the structure of living beings has to apply reductionistic strategies, that is to say to analyse and to 'decompose' the systems. That is true to anatomists, physiologists, molecular biologists, biochemists, and geneticists. Besides, also researchers in the fields of taxonomy and systematic botany and zoology have to use reductionistic strategies in order to get some knowledge about the systematic position of a plant or an animal. In short: Methodological reductionism, i.e. 'going down the scale' in the hierarchically organized living systems 'going down' from organisms to organs, from organs to cells, and from cells to molecules is the everyday business of biologists who are doing empirical research. As I already mentioned, without methodological reduction we would not know anything about the nature of inheritance, we would not have any idea of the genetic code and the transmission of genetic information from one generation to the other. I have chosen genetics as an example for both successful methodological and successful epistemological reduction. As to methodological reduction the success is most evident: Reducing the organism to its particles (i.e. molecules) has led to findings of greatest importance to our understanding of the intrinsic nature of living

systems. In a way, the discovery of the structure of the DNA was a step towards an understanding the 'secret of life'. Thus, *molecular genetics* –compared to classical genetics (MENDEL)– has been a progress. But it has been a progress for epistemological reason too. The reduction of classical genetics to molecular genetics is indeed a good example for a successful epistemological reduction in the life sciences (for details see, e.g., HULL, 1974; MOHR, 1977).

Classical genetics is primarily transmission genetics; its scope is more narrow than the range of molecular genetics. Remember that geneticists have discovered at the molecular level the most fundamental and universal principles of inheritance. Notwithstanding the objections expressed by some philosophers of biology (HULL, 1974; ROSENBERG, 1985), I think that classical genetics can indeed be regarded as a special, limited case of molecular genetics. Molecular biologists intend to cover transmission genetics and developmental genetics. As far as I can see they are successful in doing so. As MOHR, who is himself a molecular biologist, puts it:

> With regard to the problem of 'reduction', I feel that molecular biology will replace in practice classical transmission genetics as far as possible without any enforcement. Classical genetics will not be fully displaced since for many statements in transmission genetics the terms and laws of classical genetics are more useful than the corresponding statements of molecular biology (MOHR, 1977, p. 101).

Another example for successful epistemological reductionism in biology is the reduction of DARWIN's theory of natural selection to *synthetic theory*. For the advocates of synthetic theory use models of population biology and because they have explained a wider domain of phenomena than DARWIN did, DARWIN's theory can be derived from the central theses of synthetic theory as a special case. Moreover, many of his statements and explanations may be transformed into terms of population biology. Synthetic theory, however, now turns out to be a special case of a broader theoretical account of evolution, i.e. a *systems theory of evolution* (see (RIEDL, 1977; WAGNER, 1985; WUKETITS, 1985a). This approach to organic evolution is a theory taking cognizance of both external selection (i.e. natural selection in DARWIN'S sense and in the sense of synthetic theory) and internal selective agencies (i.e. organismic constraints to evolution).

In short, biology has progressed towards more and more general theories, theories which cover a broad area of (biological) research and to which

separate (biological) facts may be related. The most universal biological concept is the concept of evolution. «Nothing in biology makes sense except in the light of evolution» (DOBZHANSKY et al., 1977, p. v)—and as the development of evolutionary conceptions since DARWIN has shown, biology tends towards more comprehensive theories of evolution. As to epistemological reduction we can state, then, that with every successful step of the reduction our insight into the structure and organization of the living world gets deeper.

4. LIMITS TO REDUCTIONISM IN BIOLOGY

Having praised reductionistic research strategies, I shall now make my point as to the limits to reductionism in biology. As indicated above, at the level of epistemological reduction one should keep in mind that certain biological concepts cannot be sufficiently transformed into physical ones. Thus, epistemological reduction/reductionism is indeed successful within the area of biological research, but it is not and cannot be successful, if one is trying to reduce biological concepts and theories to physical ones.

This limit to reductionism has been caused by the fact that there is a great variety of concepts specific to biology. Let me just hint at the question *what for*? This is the typical question of biology at the organismic level, stipulating functional and, particularly, teleological explanations (see e.g. LORENZ, 1978; SIMPSON, 1963; WUKETITS, 1978, 1980, 1983). If you are looking for an example, it may suffice to analyse but one specific biological statement: «Cats exhibit crooked, pointed claws, with which they catch mice». This statement cannot be translated into the language of physics without loss of meaning. That's simply because claws are a systems property of cats. To be sure, a physicist should be able, e.g., to reckon the velocity of a cat's catching mice, and things like that, but when doing so, he will get physical or mathematical results which say little about the specifity of cats as biological systems. Certainly, a cat when catching mice cannot brush aside physical laws and constraints (like the law of gravitation etc.), but such laws and constraints do not explain the cat as a whole organism, and these laws (and constraints) do not suffise to explain the specific behaviour of the organism. Let me give another example which shows both the limits to epistemological reductionism and the fallacy of ontological reductionism. Human walking is determined and constrained by biological

structures and functions, i.e. bones, muscles etc., that is to say by the anatomy and physiology of our locomotory apparatus. This apparatus can be reduced, then, to chemical (molecules) and, in the last instance, physical (atoms) structures. I do not think that any scientist can doubt that his (her) walking is indeed determined by biological, chemical and physical factors. Reducing 'walking' to chemical and, finally, to physical laws, however, does not mean that, then, it is sufficiently explained. Particularly, there is no chemical and physical explanation of my walking towards a certain destination. If I want to go for a walk in a park, I –as a matter of fact– need my legs, and their molecules and their atoms. But nobody would be able to infer my going for a walk in a park from the biological, chemical and physical structure of my legs. Clearly, we have to distinguish between different levels of the organization of living beings and their functions. It is true that *the whole is more than its parts* and even more than the *sum of its parts*.

The behaviour of any organism cannot be inferred from its molecules and atoms. 'Behaviour' is always a systems property of the whole organism — and not just a property of its molecules and atoms. Hence the epistemological reduction of behavioural science to chemistry (and physics) would be a hopeless undertaking. Reductionism here is limited by the phenomena of organismic behaviour themselves. As WEISS (1969, p. 368) puts it:

> There is no phenomenon in a living system that is not molecular, but there is none that is only molecular, either.

All things considered, I should say that

(a) *ontological* reduction is a 'bad philosophy' and that those claiming for this type of reduction have simplified nature;
(b) *methodological* reductionism is a useful and important research strategy, but that it does not allow the conclusion that reduction for methodological reasons justifies reduction at the ontological level;
(c) *epistemological* reductionism is what the biologist (as any other scientist) should aim at in order to find the fundamental principles and laws inherent in living systems, but that the reduction of biology to chemistry (and physics) is neither possible nor desirable.

The reduction of one discipline to another, say of biology to physics, would impoverish the potential of scientific explanation. I think that

pluralism in approaches to an understanding of the phenomena of the living world is more fruitful.

5. THE NEED FOR SYNTHETIC THINKING

Besides reductionistic research strategies –be it at the ontological, at the methodological or at the epistemological level– the synthetic approach is needed. That means that, despite successful (methodological and epistemological) reduction, we should never forget that any organism is a complex system, which is *hierarchically* organized and which exhibits complex interaction between its subsystems. RIEDL (1977, p. 360) says that

> we must accept a flow of cause and effect in two directions, up and down the pyramidal of complexity. Then we should also accept causality in living beings as a system in which effects may influence their own causes. Biology would then at last accept causality as a network rather than as a one-way chain.

Studying the molecular basis of life is indeed important, but the biologist should not forget that he (she) is concerned with particles of something which *lives* and that any *living* organism is more but a heap of molecules; after all, biology is and should remain to be the science of life (and not just the study of molecular activities) (see on this also WUKETITS, 1985b).

Analytical and synthetic thinking or, to use SIMPSON'S terminology (SIMPSON, 1963), reduction and composition (reductionism and 'compositionism') are two different ways of looking at living systems. But in order to obtain as much information as possible, these approaches should be linked together. As long as you look at the whole organism, you will have no idea of the organism as a whole. That might be a truism. But remember that in many biology courses at our modern universities reductionistic, analytical thinking is fostered at the expense of synthetic thinking — at the expense of a deeper insight into the living world. Hence it might be useful, to consider from time to time the meaning of synthetic, 'compositionist' thinking.

6. WHAT ABOUT HOLISM?

I have admitted that reductionism (at the methodological and at the epistemological level) has been a successful research strategy in science. But I am aware of the fact that any reduction in science necessarily leaves an unresolved, i.e. 'unreduced' residue. (Remember POPPER'S suggestion quoted above). So what about *holism*? SATTLER (1986, p. 223) states that

> facing the fact that reduction of biology to physics is unattainable at present and for many reasons probably also in the future, one may question whether it is desirable to concentrate our efforts on reduction. It may be easier and more successful to build general and comprehensive theories on the basis of General System Theory and other general approaches that are not reductionist.

I have much sympathy for *system theory* and *system thinking* (see e.g. WUKETITS, 1978, 1983, 1985b), and I think that BERTALANFFY (1973) did a decisive step towards the systems approach in biology, and that this approach can help us to develop a profound understanding of the complex phenomena of life. BERTALANFFY's conception is a 'holistic' (or an 'organismic') one. However, in some circles holism has a bad tradition. This will not come as a surprise, since many holists were indeed vitalists. But one should keep in mind that, on the other side, there is a 'materialist tradition' within holistic thinking which is compatible with the tenets of modern system theory. What I have in mind, is the assertion that matter exhibits the tendency «to construct entities of ever increasing complexity» and that this complexity is «the outcome of the *organization* of matter on many superimposed levels» (LØVTRUP, 1983, p. 444). Hence holism is not to be confused with vitalism; and it is not necessarily contradicted by reductionism. Methodological reductionism has shown clearly that there are different levels of organization inherent in any living systems. The systems approach is a *multi-level* approach to living systems, combining analytical with synthetic thinking (BUNGE, 1977). Therefore, it is worthwhile to foster the holistic approach as far as it coincides with the principles of general system theory and as far as it is built on scientific (and not metaphysical!) premises.

7. CONCLUSION

I conclude that reduction/reductionism is still an interesting issue in the philosophy of biology, and that some of the problems in its context require further discussions. In particular, I feel that many biologists are not yet aware of the fact that there are limits to reductionism and that any reduction should be complemented by the holistic approach. Reductionism and ‘compositionism’ do not exclude each other; they only offer two different faces of one and the same phenomenon.

Might be that a biologist who is familiar only with the ‘hard facts’ considers reflections of this kind generally as obsolete. Should this be the case, then I should remind you that the topic also has a practical aspect.

Listen to MOHR (1977, p. 95):

> Research funds are dwindling rapidly throughout the world. The competition between the different fields of science will become stronger. Some fields will disappear completely... Under these circumstances, a fair comparison of the logical status of competing disciplines becomes crucial. If scientists are not willing to describe clearly the structure of and the relationship between different fields, the future of science will be determined by prejudice and incidental experience of the members of legislatures, granting agencies, and governmental administrations.

We should think about the consequences!

Wien, October 1987.

REFERENCES

AYALA F. J., 1968 — Biology as an Autonomous Science. *Am. Sci.*, **56**, 207-221.

AYALA F. J., 1974 — Introduction. In: AYALA F. J. and DOBZHANSKY T. (eds.): *Studies in the Philosophy of Biology*. Macmillan, London (pp. vii - xiv).

BERTALANFFY L. V., 1973 — *General System Theory*. Penguin Books, Harmond-sworth.

BUNGE M., 1977 — General Systems and Holism. *General Systems*, **22**, 87-90.

DOBZHANSKY T., AYALA F. J., STEBBINS G. L., VALENTINE J., 1977 — *Evolution*. Freeman, San Francisco.

HOYNINGEN-HUENE P., WUKETITS F. M. (eds.), 1987 — *Molecules and Organisms*. D. Reidel, Dordrecht-Boston (in preparation).

HULL D., 1974 — *Philosophy of Biological Science*. Prentice-Hall, Englewood Cliffs.

JACOBS J., 1986 — Teleology and Reduction in Biology. *Biol. & Philos.*, **1**, 389-399.

LORENZ K., 1978 — *Vergleichende Verhaltensforschung*. Springer, Vienna-New York.

LØVTRUP S., 1983 — Reduction and Emergence. Rivista di Biol., **76**, 437-451.

MEDAWAR P. B., MEDAWAR J., 1983 — *Aristotle to Zoos*. Harvard University Press, Cambridge, Mass.

MOHR H., 1977 — Lectures on Structure and Significance of Science. Springer, Berlin-heidelberg-New York.

NAGEL E., 1961 — *The Structure of Science*. Harcourt, Brace & World, New York.

POPPER K. R., 1974 — Scientific Reduction and the Essential Incompleteness of All Science. In: AYALA F. J. and DOBZHANSKY T. (eds.): *op. cit.* (pp. 259-183).

RIEDL R., 1977 — A Systems–Analytical Approach to Macro-Evolutionary Phenomena. *Quart. Rev. Biol.*, **52**, 351-370.

RIEDL R., 1985 — *Die Spaltung des Weltbildes*. Parey, Berlin-Hamburg.

ROSENBERG A., 1985 — *The Structure of Biological Science*. Cambridge University Press, Cambridge-London-New York.

SATTLER R., 1986 — *Biophilosophy*. Springer, Berlin-Heidelberg-New York.

SIMPSON G. G., 1963 — *This View of Life*. Harcourt, Brace & World, New York.

WAGNER G. P., 1985 — Über die populationsgenetischen Grudlagen einer Systemtheorie der Evolution. In: OTT J. A., WAGNER G. P. and WUKETITS F. M. (eds.): *Evolution, Ordnung und Erkenntnis*. Parcy, Berlin-Hamburg (pp. 97-111).

WEISS P. A., 1969 — The Living System: Determinism Stratified. *Stud. Gen.*, **22**, 361-400.

WUKETITS F. M., 1978 — *Wissenschaftscheoretische Probleme der modernen Biologie*. Duncker & Humblot, Berlin.

WUKETITS F. M., 1980 — On the Notion of Teleology in Contemporary Life Sciences. *Dialectica*, **34**, 277-290.

WUKETITS F. M., 1983 — *Biologische Erkenntnis: Grundlagen und Problem*e. Fischer, Stuttgart.

WUKETITS F. M., 1985a — Die systemtheoretische Innovation der Evolutionslehre-Historische und erkenntnislogische Voaussetzungen einer Theorie der Systembedingungen der Evolution. In: OTT J. A. et al. (eds.): *op. cit.* (pp. 69-81).

WUKETITS F. M., 1985b — *Zustand und Bewusstsein*. Hoffmann und Campe, Hamburg.

WUKETITS F. M., 1987 — Synthetic and Analytical Thinking. *Z. Anal. Chem.*, **326**, 320-323.

• The Italian text, to be found in the Bilingual Edition, was omitted.
The page numeration is the same as in the Bilingual Edition.